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Towards establishing similar assembly interfaces for a mixed-product assembly system

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Abstract

Developing a mixed-product assembly line (MPAL) is an elaborate task due to the complexity raised by product variety. This paper proposes that securing similar assembly interfaces across distinct product families is an essential requirement of MPALs which facilitates flexibility and reduces complexity. The concept of similar assembly interfaces has been developed and analysed in a case study at a heavy vehicle manufacturing company. The results suggest that assembly interfaces can be defined according to generic assembly operation steps: pick, place and attach. The paper highlights the need for development of a cross-functional methodology to analyse and establish similar assembly interfaces.

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Keywords: Flexibility; mixed-product assembly line; product design; product variety; complexity

1. Introduction

The modern manufacturing world is characterised by ever-increased demands for flexibility in process, product ranges, and dealing with customers and suppliers, while having to deliver reliably and at ever lower costs [1]. To fulfil the fast changing customer demands for various and new products, and to maintain their competitive edge, manufacturing companies need to be flexible in terms of volume and variety of the products they offer. Assembly system as a critical sub-system in the manufacturing system provides one of the most cost effective approaches to realise high product variety [2]. In particular, Mixed-Product Assembly Lines (MPALs) allow creating various products in the same assembly line. In an MPAL, multiple products with only one model in each production line are produced [3]. Given the significance of an assembly system for a manufacturing system from both cost and time perspectives [4], in addition to offering high product variety, MPALs are becoming increasingly popular among manufacturing companies in various industries [2, 5]. In the last decade, some manufacturers have made product diversity their priority and have operated MPALs to meet variable demands from customers and to become more competitive in their industry [3]. In line with the shift of manufacturing system as a whole towards becoming flexible, developing MPALs supports facilitating major dimensions of flexibility; mix flexibility, volume and new product flexibility [6] in the assembly system. MPALs are both flexible and reconfigurable, since not only they save investment costs by sharing multiple products on the same assembly line [7], but also they absorb demand fluctuations [7, 8]. Although developing an MPAL offers various advantages in terms of creating high product variety, often it turns into a complicated task as a result of increased complexity. Product variety allows manufacturers to satisfy a wide range of customer requirements, but it can also be a major contributing factor to increased complexity in assembly [9]. Product variety and options have a significant and adverse impact on productivity, labour costs, assembly-line downtime, minor repairs and major re-workings, as well as inventory levels [10]. Therefore, the product design and the manner in which the product is developed play a critical role in reducing the complexity in assembly system. A good design saves time and cost for the product assembly with reduced components, easy assembly procedure and optimal part structures in an accessible working space of assembly tools [11]. Developing an MPAL becomes even more challenging when a number of already exiting distinct product families with various models

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need to be produced on the same assembly line. In such a case, product design counts as a major contributing factor in increasing complexity and therefore limits mix and new product flexibility in an MPAL. Although various Concurrent Engineering (CE) methodologies such as DFA techniques have been extensively discussed in recent decades, they do not directly address the recent challenges in aligning product design with requirements of an MPAL. Given the increasing urge to create flexibility through MPALs, tackling this challenge is of a high interest for many manufacturing companies which are moving towards establishing flexibility in their assembly systems. To address this issue, the purpose of this paper is to explore the requirements of an MPAL that are essential to performing assembly operations and must be fulfilled by product design. The results propose that to facilitate flexibility and reduce complexity in assembly operations in an MPAL, similar assembly interfaces must be defined across distinct product families. Further, the paper underlines the need for development of a cross-functional methodology between assembly and product related functions in order to both analyse and establish increased similarity of assembly interfaces across distinct product families, as requirements of an MPAL for product design.

2. Reflecting assembly systems' requirements via CE

To simultaneously consider all the elements of product lifecycle when designing and developing a product, CE has been developed as a philosophy that replaces the traditional sequential product design and development processes. CE is in fact a manufacturing philosophy that provides manufacturing concerns with an effective means of organising and coordinating all the processes towards minimum lead time and development cost, while maintaining product quality to the total satisfaction of the customer [12]. Product design is driven by the product requirements [13] and a product needs to be considered from multiple perspectives to satisfy the many conflicting requirements that must be addressed during product development [14]. Requirements of an assembly system are an essential part of the requirements that must be dealt with during product development process. Assembly process information and knowledge are required to determine product lifecycle management requirements that have to be taken into account during the product development process using CE philosophy [15]. Various Design For Manufacture (DFM) and Design for Assembly (DFA) techniques have been developed (see e.g.[16]) as well-established and important CE imperatives [17] to secure manufacturing and assembly aspects in product design and development process. Some of the general advantages and shortcomings of DFM/DFA techniques as suggested in the literature are presented in Table 1. Decisions related to manufacturing and assembly are also reflected through product's architecture. Product architecture is regarded as one of the development decisions that most impacts a firm's ability to efficiently deliver high product variety, and is closely linked to decisions about marketing strategy, manufacturing capabilities, and product development management [18]. Product architecture influences how products are assembled, it influences how

Table 1. Strengths and shortcomings in application of DFA/DFM techniques.

	Application of DFA/DFM techniques
Strengths	Simpler and more reliable products [17].
	Less expensive products to manufacture and assemble [17]
	Reduced product development lead time, product development cost, and improved product quality [12].
	Cost effective product design [13].
Shortcomings	Results based on estimations and general rules [14]
	Designers' tendency to focus more on the functionality of product rather than DFA [15]
	Almost finished products required for analysis[14]
	Regarded as a restriction of the freedom of the designer [16].
	Difficult and expensive maintenance and upgrading of products [13]
	Hardly applied in the current design practice [16]
	Gaps in management of various technical entities and control of information/decision/rationale flow through the product lifecycle [17]
	Implementation requires a change of attitude, of both the designers and the management [16].

flexible those assembly processes are to product changes, and it influences how products are distributed [22]. Nevertheless, despite the existing techniques for considering assembly system requirements in product design and due to their shortcomings, the matter is still of high practical interest and theoretical relevance. Though much work has been carried out to address assembly line issues over the decades, little has been done to bridge the link between product design and assembly system design [23]. The challenge might reflect the fact that in practice, it is often difficult for the companies to have a shared understanding of what needs to be developed, and so specifications contain ambiguities in describing the product requirements [19]. The review of accessible literature has also shown a clear lack of integration effort in addressing product modularity and assembly system design [23]. Given the issue of flexibility, requirements of an MPAL -as a flexible assembly system- for product design, and how they must be considered in product design have not been regarded in DFA and other similar existing CE techniques and needs to be further investigated.

3. Case description and research design

To fulfil the purpose of this paper, a real-time case study in a leading heavy vehicle manufacturing company with more than ten different product families and over two hundred different product models has been performed. A case study is a preferred scientific research method to closely investigate and understand a specific phenomenon within its natural context [24]. The case company has several manufacturing plants around the globe and aims to move towards establishing a regional industrial footprint. Following this global strategy in the case company allows producing various mix of distinct product families in each and every assembly line across all the manufacturing plants. Hence, products will be produced closer to the customer and consequently short delivery lead-times to customer, less transportation costs and less tied up capital are expected. In line with the new strategy, the case company has focused on increasing similarity of assembly operations among its diverse range of product families through a project, called AI project. At the time of this study, the existing assembly lines in the case company were semi-automatic Mixed-Model Assembly Lines (MMALs) in which most of the operations were performed by the assemblers. Following the new strategy, the case company aims to eventually make a transition from MMALs to MPALs in all its manufacturing plants. The conducted case study, focused on AI project in the case company over an 8-month study period from the beginning until the end of the project. The primary motive in selecting AI project as the case in this study has been the focus on formulating the key requirements of an MPAL for product design to secure flexibility and reduce complexity in assembly operations. The data collection in this case study was made possible through direct observations, in-depth interviews with key participants, questionnaires and full access to AI project's documents. To make the observations, the researchers participated in all the project's meetings and workshops during and over an 8-month study period, kept diary of the discussions, and recorded and transcribed some of the meetings. The questionnaire focused on collaboration between assembly function and product related functions (e.g. product platform, technology platform, and product architecture) with regards to the current status of presenting requirements of MMALs for product design, as well as developing and presenting requirements of an MPAL for product design. The questionnaire consisted of thirteen questions designed as both open questions and Likert style rating questions on a scale of 5 (1 indicating the lowest and 5 referring to the highest rate). All members of the cross-functional project team in AI project participated in the study as the respondents of the questionnaire. The cross-functional project team in AI project included manufacturing research manager, assembly managers, production engineers, technology platform and modular design support manager, product platform manager, manufacturing consultant and product architecture global manager. In total, six respondents (67% of the respondents) belonged to assembly function while the rest of the respondents belonged to product related functions in the case company. Details regarding data collection and sources of evidence applied in the case study are presented in Table 2.

Table 2. Data collection sources and evidence.

Data source	Techniques	No.	Participants/ respondents	Duration (min)
Observations	Meetings	13	Cross-functional project team	30-150
	Workshops	4	Cross-functional project team	240-300
	Informal discussions	Several	Cross-functional project team	
Interviews	In-depth interview	3	AI project manager	20-45
Questionnaires	Questionnaires	9	All cross-functional project team members	

4. Empirical findings

The case company intends to reach full flexibility to adapt to changing market demands in terms of mix, new product, and volume via MPALs. The ultimate goal with AI project was to enable similar operation steps for all the vehicles by reuse of assets for various products through sharing fixtures and tooling, equipment, sub-assembly flows, and main assembly which will also lead to reduction in floor space needs. In AI project, assembly operations in final assembly of three vehicle modules (powertrain, axel, and cab modules) in eight different product models were analysed. These eight product models belonged to four distinct product families in the case company.

4.1. Presentation of MMAL's requirements for product design

In the case company, the requirements of the existing MMALs are often presented to the product development projects through few main approaches; DFA procedures, product design guidelines, product architecture requirements, and product development project meetings. According to most of the respondents, in order to present the requirements of the assembly systems, often a combination of various approaches is currently taken. DFA procedures were mentioned by 2 respondents (response percent of 22%), product design guidelines by 5 respondents (response percent of 56%), product architecture requirements by 2 respondents (response percent of 22%), and product development project meetings by 7 respondents (response percent of 78%). All the respondents from the product related functions only pointed out "product development project meetings" as the current approach for presenting requirements of the existing MMALs. On the other hand, the respondents from the assembly function selected a combination of all the various approaches (e.g. DFA procedures, product design guidelines, product architecture requirements, and product development project meetings).

"In order to present the assembly system's requirements for product design, we try to use all the available approaches", an assembly manager shared his point of view.

The product development process in the case company consists of six main consecutive phases; Planning and Pre-study (PP), Concept Development (CD), Detailed Development (DD), Final Development (FD), Ramp-up (Ru), and Follow-up (Fu). Additionally, Business Opportunity (BO) and Feasibility Study (FS) are considered as the pre-development phases completed prior to start of the Pre-study phase, as the first phase in product development process. The approaches through which requirements of the MMALs are currently presented to the product development projects are adopted through various stages of product development process. The respondents marked the applicability of each approach for presenting MMALs requirements during various stages of product development process, as shown in Fig. 1.

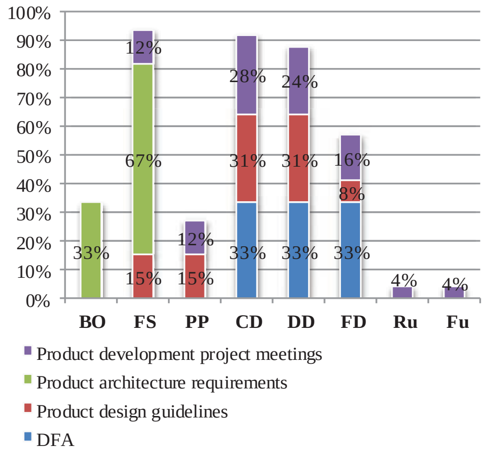

Fig. 1. use of each approach during each development phase, according to the average response rate

4.2. Development and presentation of MPAL's requirements for product design

"MPAL's requirements for product design need to be developed at least broadly, prior to product development project's start. In fact, development of such requirements supports the increased speed in product development project" a manager of a product related function elaborated. Identification and development of clear requirements of an MPAL, with regards to product design parameters, must be carried out early in product development process. Accordingly, application of DFA procedures is regarded as more appropriate for the later phases of product development process. In order to encourage the early inclusion of these requirements, open communication between assembly and product related functions, on regular basis, must be established. As a means of communication, holding face-to-face meetings and direct involvement of design engineers is crucial to regard the requirements of an MPAL as an indispensable part of product development process. Additionally, by offering high traceability features, IT solutions can be used to support the MPAL's requirements for product design.

Few opportunities and challenges have been identified in connection to developing generic requirements of an MPAL for product design shared among distinct product families. The identified opportunities in this regard are:

- Considering assembly aspects early in a product development project
- Design of modular products
- Raising design engineering competence
- Boosting cross-functional collaboration
- Easy fulfilment of common and well-defined requirements in a product development project
- Increasing commonality among distinct product families
- Increasing efficiency in assembly system
- Allowing various mix of products on the assembly line

The identified challenges of developing requirements of an MPAL are:

- Establishing a common vision across distinct product families
- Facilitating communication across various functions in the company
- Planning and creating well-established concept and assembly requirements prior to the start of product development project
- Selecting between various requirements across distinct product families based on the trade-offs between requirements
- Maintaining traceability, quality and consistency of the defined requirements
- Ensuring acceptance of assembly requirements in a product development project

4.2.1. Similar assembly interfaces

Three main generic requirements of an MPAL, which must be fulfilled via product design, have been recently identified as: following a common assembly sequence, use of common parts, and establishing similar assembly interfaces across various product models from distinct product families. These requirements of an MPAL for product design were rated with regards to their significance for an MPAL and according to their rating average: similar assembly interface (4.38), common assembly sequence (4.17), and common parts (3.63). Developing a common assembly sequence allows establishing similar assembly interfaces across distinct product families and various product models.

Assembly interface is defined based on three basic movements in assembly operations: picking the part/module, placing the part/module and attaching the part/module. All of these three steps in assembly operations are described as the activities that add value for the customer. Considering several existing distinct product families in the case company today, and the various ranges of product models within each product family, there is a huge difference in how these three steps in assembly operations are performed both across distinct product families and within each product family. Due to the huge product variety and in order to enable an MPAL, there is a need to define strategies to establish similar assembly interfaces across various product families in the case company. *"Different approaches that define modularisation and interface strategies already exist in automotive, truck, airplane, and ship industries. However, it is very difficult to find similar approaches in construction vehicle industry", an assembly expert elaborated.* Today, for describing assembly interfaces in the case company, no structured methodology is yet available. Nevertheless, various assembly methodologies are described through assembly drawings and assembly work instructions. Developing similar assembly interfaces across distinct product families has been identified to create opportunities and pose challenges which involve both assembly system and product design. The identified opportunities and challenges created by developing similar assembly interfaces for both assembly system and product design are presented in Table 3.

Table 3. Opportunities and challenges related to developing similar assembly interfaces across distinct product families for assembly system and product design.

	Opportunities related to developing similar assembly interfaces	Challenges related to developing similar assembly interfaces
Assembly system	Facilitates learning of assembly operations' know-how Standardises assembly operations across distinct product families Enables sharing of assembly tooling and equipment Enables mix and new product flexibility Reduces complexity in assembly operations Increases efficiency in assembly system Improves ergonomics in assembly operations	Achieve effective shared assembly methods across distinct product families Gain early understanding of other stakeholders' requirements Raise awareness about profitability of developing similar assembly interfaces across distinct product families in the company Engage all the related functions in the company
Product design	Enables design standardisation and similar design solutions Enables saving cost via product design Provides insights into assembly concerns for design team Enables re-use of the best practice across distinct product families Reduces workload and time spent on design, development and maintenance activities Increases re-use of parts, not only limited to different product models but also across distinct product families	Maintain functionalities of various products Keep similar assembly interfaces on the existing products and creating them on the new products Avoid conflicting requirements from other stakeholders Coordinate and communicating at a cross-functional level in product development projects Fulfil the need for developing a cost saving analysis

The respondents in the case company proposed when, according to the different phases in product development process, similar assembly interfaces need to be considered. The response percentages show which phase in product development process is regarded by the respondents as the more appropriate phase to include similar assembly interfaces: business opportunity (12%), feasibility study (28%), planning and pre-study (12%), concept development (20%), detailed development (16%), final development (8%), follow-up (4%), and production ramp-up (0%). Additionally, the response percentages from the respondents highlight how similar assembly interfaces must be specified using various approaches; DFA (44.4%), product design guidelines (55.6%), product architecture requirements (77.8%), and product development project meetings (11.1%). According to the respondents, in order to define, record and communicate the requirements of an MPAL for product design, product architecture and similar assembly interfaces must be developed simultaneously.

5. Analysis and discussion

In line with the purpose of this paper, the findings reflect a cross-functional perspective on the requirements of an MPAL that are essential to performing assembly operations and must be fulfilled by product design. The case company is shifting towards establishing the major dimensions of flexibility [6] in its assembly systems through establishing MPALs. In order to align product design with assembly system's requirements [15, 19, 20], various common CE approaches [18] are known to be in-use to present MMAL's requirements to product development projects in the case company. These approaches have been identified as: product development project meetings, product design guidelines, DFA procedures, and product architecture requirements, consecutively and according to their frequency of application in the case company. Based on the findings, assembly function tends to adopt various approaches for presenting MMAL's requirements for product design, while the product related functions regard product development project meetings as the main means of accessing MMAL's requirements. This finding highlights a gap between assembly and product related functions standpoints on how to present assembly system's requirements for product design. Among all the various identified approaches, DFA procedures and product design guidelines show a rather low application in terms of reflecting the MMAL's requirements. Concept development and detailed development phases respectively have been identified as the phases in which the requirements of an MMAL for product design are most frequently presented in product development process.

On the other hand, the requirements of an MPAL for product design need to be developed and included early in the product development process. To realise this early inclusion, open communication between assembly and product related functions is essential. The early development and presentation of an MPAL's requirements not only supports increased mix flexibility and efficiency in the assembly system, but also have organisational impacts such as raising design engineering competence. However, the challenges regarding development and presentation of these requirements mostly revolve around the trade-offs between MPAL's and other stakeholders' requirements, maintaining a common view across distinct product families, and securing tractability and solidity of these requirements during various phases of product development process. Through the presented case study, the need for developing similar assembly interfaces across distinct product families in the heavy vehicle manufacturing industry was highlighted. To support mix, new product and volume flexibility of an assembly system through establishing MPAL, and to reduce complexity, similar assembly interfaces must be developed across distinct product families. Similar assembly interfaces in a semi-automatic MPAL are defined according to three main value adding basic steps in assembly operations; pick, place and attach. Development of similar assembly interfaces provides shared opportunities such as increased standardisation for both assembly system and product design, while it also poses shared challenges such as handling the trade-offs between the requirements, providing profitability analysis, and creating common understanding in the organisation. The findings also suggest a link between three identified requirements of an MPAL for product design. Development of a common assembly sequence across distinct product families is an essential prerequisite for developing similar assembly interfaces, and developing similar assembly interfaces also leads to increased commonality of parts and reduced part numbers. Similar assembly interfaces, as the requirement of an MPAL for product design, must be considered as early as during feasibility study and prior to the start of product development process, whereas MMAL's requirements are mostly considered during concept and detailed development phases. The lower applicability of DFA procedures for presenting similar assembly interfaces reflects some of the previously discussed shortcomings of these procedures [13, 14, 16, 17], especially in terms of early applicability in product development process [14]. Moreover, the finding regarding the simultaneous development of product architecture and similar assembly interfaces highlights the essential role of product architecture in early development, record and presentation of similar assembly interfaces in product development process. Thus, this finding implies the need for development of a cross-functional methodology shared between assembly and product related functions to define, analyse, and establish similar assembly interfaces of an MPAL across distinct product families, and as early as during the feasibility study phase.

6. Conclusions

Through a case study in heavy vehicle manufacturing company, this paper proposes that establishing similar assembly interfaces across distinct product families is essential for development of an MPAL supporting flexibility and reducing complexity in an assembly system. Similar assembly interfaces must be developed prior to the initiation of product development process during the feasibility study stage. This research study challenges the application of common techniques such as DFA for development and presentation of similar assembly interfaces. As an outlook for future research, the paper underlines the need for developing a methodology shared between assembly and product related functions to focus on fulfilling similar assembly interfaces via product design and across distinct product families.

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References

[1] Zhang Z. Manufacturing complexity and its measurement based on entropy models. International Journal of Advanced Manufacturing Technology. 2012;62:867-73.

[2] Hu SJ, Ko J, Weyand L, Elmaraghy HA, Lien TK, Koren Y, et al. Assembly system design and operations for product variety. CIRP Annals - Manufacturing Technology. 2011;60:715-33.

[3] Lin D-Y, Chu Y-M. The mixed-product assembly line sequencing problem of a door-lock company in Taiwan. Computers & Industrial Engineering. 2013;64:492-9.

[4] Samy S, ElMaraghy H. A model for measuring complexity of automated and hybrid assembly systems. The International Journal of Advanced Manufacturing Technology. 2012;62:813-33.

[5] Shewchuk JP, Moodie CL. Definition and classification of manufacturing flexibility types and measures. International Journal of Flexible Manufacturing Systems. 1998;10:325-49.

[6] Bengtsson J, Olhager J. Valuation of product-mix flexibility using real options. International Journal of Production Economics. 2002;78:13-28.

[7] Hu S, Zhu X, Wang H, Koren Y. Product variety and manufacturing complexity in assembly systems and supply chains. CIRP Annals-Manufacturing Technology. 2008;57:45-8.

[8] Wang H, Zhu X, Hu SJ, Lin Z, Chen G. Multi-objective optimization of product variety and manufacturing complexity in mixed-model assembly systems. Journal of Manufacturing Systems. 2011;30:16-27.

[9] Samy SN, ElMaraghy H. A model for measuring complexity of automated and hybrid assembly systems. International Journal of Advanced Manufacturing Technology. 2012;62:813-33.

[10] Sarkis J. An empirical analysis of productivity and complexity for flexible manufacturing systems. International Journal of Production Economics. 1997;48:39-48.

[11] Kang X, Peng Q. Data integration from product design to assembly planning in a collaborative environment. International Journal of Manufacturing Research. 2010;5:120-37.

[12] Ulrich KT, Eppinger SD. Product design and development, . Singapore: McGraw-Hill Higher Education; 2012.

[13] Edwards K. Towards more strategic product design for manufacture and assembly: priorities for concurrent engineering. Materials & Design. 2002;23:651-6.

[14] Stadzisz P, Henrioud J. An integrated approach for the design of multi-product assembly systems. Computers in Industry. 1998;36:21-9.

[15] Demoly F, Yan X-T, Eynard B, Gomes S, Kiritsis D. Integrated product relationships management: a model to enable concurrent product design and assembly sequence planning. Journal of Engineering Design. 2012;23:544-61.

[16] van Vliet HW, van Luttervelt K. Development and application of a mixed product/process-based DFM methodology. International Journal of Computer Integrated Manufacturing. 2004;17:224-34.

[17] Demoly F, Dutartre O, Yan X-T, Eynard B, Kiritsis D, Gomes S. Product relationships management enabler for concurrent engineering and product lifecycle management. Computers in Industry. 2013;64:833-48.

[18] Nategh M. Concurrent engineering planning on the basis of forward and backward effects of manufacturing processes. International journal of production research. 2009;47:5147-61.

[19] Kerr C, Roy R, Sackett PJ. Requirements management: an enabler for concurrent engineering in the automotive industry. International Journal of Production Research. 2006;44:1703-17.

[20] Gunendran A, Young RI. An information and knowledge framework for multi-perspective design and manufacture. International Journal of Computer Integrated Manufacturing. 2006;19:326-38.

[21] Boothroyd G. Product design for manufacture and assembly. Boca Raton: CRC Press; 2011.

[22] Yassine AA, Wissmann LA. The implications of product architecture on the firm. Systems Engineering. 2007;10:118-37.

[23] Xu Z, Liang M. Integrated planning for product module selection and assembly line design/reconfiguration. International journal of production research. 2006;44:2091-117.

[24] Yin RK. Applications of case study research. Thousand Oaks, CA: Sage; 2012.